Maximizing Decorative Electroplating Productivity by Optimizing the Rack Design for a Family of Ten Different Door Handles

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Costs are designed into products. Choices made on the design, the materials and indeed the manufacturing processes employed have a profound impact on the final product cost. There is a growing view, that with the availability and improvement of computer aided engineering tools (CAE), electroplating should be considered as a science rather than an art. The chemistry and physics are known and just as computing tools are regularly used for thermal, stress and fluid flow analysis in product and process development, they can also be used in optimizing racking and tooling design for plating processes. Plating thickness distribution can be predicted on a component or rack of components of any complexity. This paper describes how such a software tool was used to deliver a virtual plating plant effectively, with the goal of assessing the impact of manufacturing process decisions. In order to minimize operator costs and error, a starting premise was that a range of ten different door handle designs could be plated on a single rack design. For such a wide variation of designs from small to large, sharp-edge to smooth and curvy, arriving at a single optimized rack design was quite a challenge. A trial and error approach of building and testing racks for all ten different handle designs and a range of different decorative surface finishing options (*e.g.,* satin nickel, bright chromium, antique brass) would be inconceivable as it would be far too consuming in terms of lead time, hardware prototype racks and manpower efforts, incurring large cost and time penalties. For such a wide range of part designs and surface finishing options, Computer Aided Engineering is definitely the answer to maximize productivity.

Keywords: *Computer aided engineering, decorative chromium plating, plating rack design, copper-nickel-chromium*

Introduction

Decisions made in manufacturing, aimed at addressing product quality, productivity and cost control have a direct impact on the final product cost. In the past, key drivers included continuous reduction in costs and time to market. Now an additional challenge for suppliers is to consider the environmental impact of their decisions, not only during product life but also during manufacturing. Manufacturing choices directly affect material and energy used and indeed the effluents emitted - particularly in electroplating.

Over the past 25 years, Computer Aided Engineering (CAE) and Computer Aided Design (CAD) tools have been developed addressing initially fundamental physics, such as stress, fluid flow and heat transfer. CAE tool development then integrated these physics in order to assess more complex processes such as mold flow in plastics manufacturing up to electroplating of all types of components.

With the availability and improvement of computer aided engineering tools, electroplating should be considered as more of a science rather than an art. We at Elsyca have developed new technology and capability which enables the accurate prediction of the electrodeposited metal thickness distribution about any complex geometry. On a project basis, we have exploited this unique

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capability to design and optimize electroplating processes, tooling and racking. Our simulation platform essentially allows the import of CAD data and delivers an analysis which clearly illustrates and addresses manufacturing issues related to electroplating.

The following case describes how this technology has been challenged by delivering an optimized racking solution for a family of ten different door handles, with the goal of maximizing productivity during the decorative electroplating cycle. The case clearly illustrates how time, money and energy can be saved using electroplating simulation technology.

Rack design challenge

The starting premise for the project is that a complete range of the ten different door handle designs could be plated on one single rack design. This will enable limiting rack investments to only one type of rack instead of ten different rack types and also minimizing operator costs and error.

As can be seen in Fig. 1, there is a wide variation of door handle designs from small to large, sharp-edge to smooth and curvy. Arriving at one single optimized rack design for all door handles types is quite a challenge while trying to account for the following requirements simultaneously:

- Scrap rates should be minimized, thus reducing waste and costs.
- Production capacity should be maximized, independently from the door handle design.

A trial-and-error approach of building and testing racks for all ten different handle designs and a range of different decorative surface finishing options (*e.g.*, satin nickel, bright chromium, antique brass) would be inconceivable as it would be far too consuming in terms of lead time, hardware prototype racks and manpower efforts, incurring large cost and time penalties. For such a wide range of part designs and surface finishing options, computer aided engineering is definitely the answer to maximize productivity, enabling the creation of a virtual plating plant to try out the effect of manufacturing decisions "off-line."

Plating process and specifications

The plating process under consideration, involves the following electrochemical process steps:

- Cyanide copper strike
- Cyanide copper plate
- Semi-bright nickel
- Bright nickel
- Satin nickel
- Hexavalent chromium

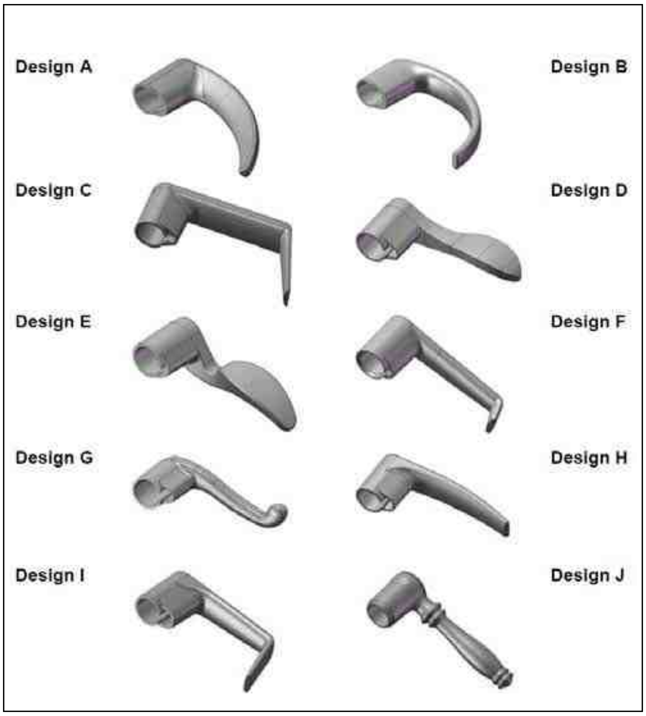

Figure 1—*Simplified CAD configuration of the ten door handle designs.*

Table 1 summarizes the thickness targets for the various metal layers. "A" type surfaces are exposed frontal view surfaces. "B" type surfaces have only exposure by side view (hence the back side of the door handles) and "C" type surfaces are not visible when mounted (bore diameter). Figure 2 provides a rough classification of the surfaces for the design "F" door handle, with "A" type surfaces in yellow, "B" type surfaces in red and "C" type surfaces in dark grey.

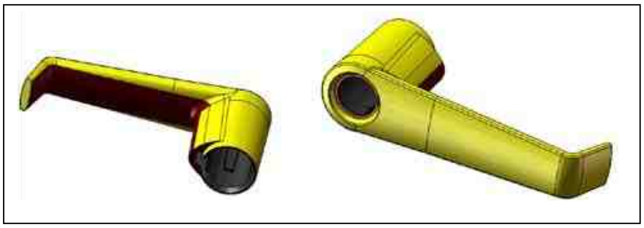

Figure 2—*Definition of "A," "B" and "C" type surfaces for door handle design "F."*

Table 1

Layer thickness targets (from *The Electroplating Handbook*) (microns)

	Cu strike	Acid Cu	Semi-Br Ni	Bright Ni	Chromium
A type	0.1 / 2.5	0.3 / 7.5	0.5 / 13.0	0.3 / 7.5	0.01 / 0.25
B type	-	-	-	-	0.002 / 0.05
C type	-	-	-	-	-

Basically, there are no specifications for the "B" type surfaces, other than that chromium coverage is required. From experience, full chromium coverage is only obtained when a 0.5-μm (19.7-μ-in.) layer is present. Otherwise, only chromium nuclei will form on the nickel, not being merged together. This will typically give the yellowish color, known as "nickel show."

On the other hand, the quality of the deposits should be maintained at any position on the door handle. If locally too high current density values are encountered, flaws will occur.

- For the copper baths, this concerns the formation of rough deposits.
- For the nickel baths, a nodular (cauliflower-like) deposit will form.
- For the chromium baths, burning will occur.

Sample process parameters for each plating step are listed in Table 2.

The plating line is cycle-designed and for that reason each plating step is voltage controlled. The process time for each plating step is fixed, and depends on the number of tank stations per plating step.

For the computer simulations of the cycle line plating steps (copper and nickel), it is important to know the overall effect of the contact and bus bar resistances, because part of the imposed voltage will be consumed as ohmic drop in the electrical network outside of the tank, and the voltage range of the rectifiers is limited. The chromium plating is performed in a separate hoist line.

Simulation of the electroplating process focuses on the semi-bright nickel and the chromium layers. The semi-bright nickel layer is typically the thickest nickel metal layer with more relative variation in thickness than occurs for the copper plating steps. In case of excessive current density, a nodular cauliflower-like growth might occur. The chromium layer is crucial since this is the thinnest layer. If the current density is too high, chromium burning might occur. Also issues of nickel show should be avoided, appearing as spots with no chromium coverage.

Evaluation of the existing situation

Figure 3 depicts the rack configuration as initially proposed. The rack contains in total, 96 parts in eight columns and six rows. The enclosing electrolyte volume and anodes (red) are also shown.

Semi-bright nickel plating step

Figure 4 shows the simulations for the semi-bright nickel step. In Fig. 4(a), the current density distribution is shown. In the red areas, current densities are higher than the threshold value for nodular nickel deposits, meaning the nodular growth could appear.

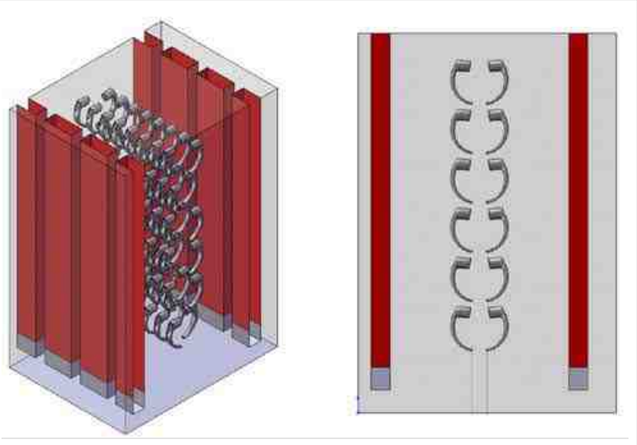

Figure 3—*CAD of a nickel plating station with a 96-part load.*

In Fig. 4(b), the edge effect over the rack is obvious. The outer door handles receive higher currents and thus higher layer thickness deposits. The red areas receive as much as 40 μm (1.57 mils) of nickel compared to a specification of 13 μm (0.51 mils). There is clearly a large variation in nickel layer thickness and thus a potentially large overconsumption of metal.

Hexavalent chromium plating step

Figure 5 shows the simulation plots for the chromium plating step. The red areas in Fig. 5(a) indicate again excessive current densities leading to chromium burning. In Fig. 5(b), the dark blue spots receive insufficient chromium, leading to nickel show, even on "B" type surfaces.

Evaluation for all door handle designs

Simulations were performed for the semi-bright nickel and chromium steps for the ten door handle designs. The results are summarized in Table 3, showing the probability of defects for the different designs with respect to chromium burn, nickel show, nickel nodular growth and the rectifier being out of range.

The several defects are caused by:

- Insufficient chromium deposition, producing nickel show
- Excessive current density, leading to chromium burn and nodular nickel growth
- Excessive rack load, causing the rectifier to be out of range

Table 2

Intended average current density values and process times as provided by the plating chemical supplier

	Cu strike	Cu plate	Semi-Br Ni	Bright Ni	Cr (VI)
Plating time	353 sec	988 sec	988 sec	449 sec	198 sec
Current density	15 - 30 A/ft^2	15 - 30 A/ft^2	40 - 50 A/ft^2	40 - 50 A/ft^2	150 A/ft^2
$\Delta V_{nominal}$	9 V	9 V	9 V	9 V	12 V

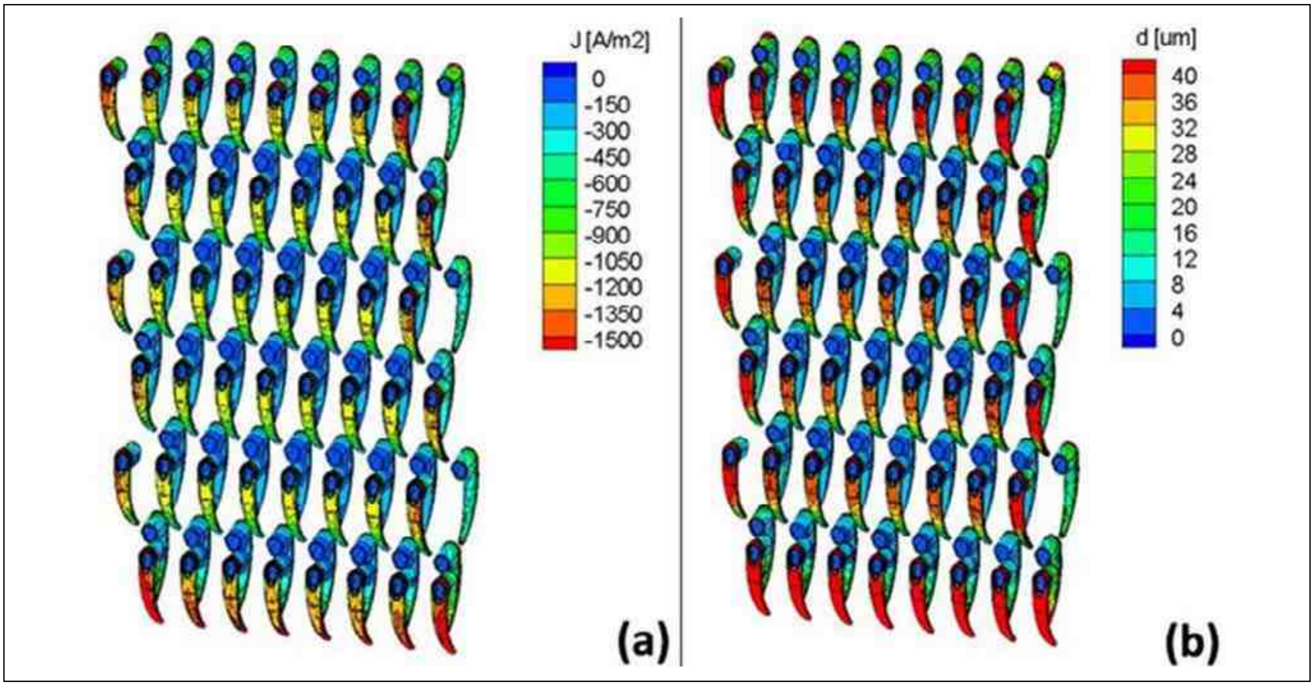

Figure 4—*(a) Semi-bright nickel current density distribution; (b) Semi-bright nickel layer thickness distribution.*

Note however, that the table, in case of a high defect probability, *e.g.*, chromium burn in design "E," does not mention how many parts of the total load will be affected. Judging from the plots in Fig. 5, this will however easily be 50%, namely all of the affected parts at the outer edges.

Conclusion for the existing configuration

The proposed rack configuration is not acceptable, in view of the number of parts that should be scrapped because of quality defects. Should this design be adopted, the predicted scrap rate of 42% would result in a significant cost.

Obviously, alternative rack configurations should be considered. Table 4 gives nine alternative rack configurations (based on general rack plating experience) and describes how these configurations are different from the initial one.

Simulation enables a quick evaluation to determine if there is any improvement over the initial rack configuration. For these simulations, the most challenging door handle design was selected (design "C"), and the nickel show defect on the backside of the door handle was selected as the criterion to judge if there was any improvement.

Table 3
Overview of defect categories as observed for each part program for the existing rack configuration

Part	Probability of Defect			
	Chromium Burn	Nickel Show	Nodular Ni Growth	Rectifier ΔV out of range
Design A	High	High	High	High
Design B	High	High	High	High
Design C	High	High	High	High
Design D	High	Medium	High	Medium
Design E	High	Medium	High	Medium
Design F	Medium	Medium	High	Medium
Design G	Medium	Low	Medium	Medium
Design H	Medium	Low	Medium	Low
Design I	Medium	Medium	Medium	Low
Design J	Medium	Low	Medium	Medium

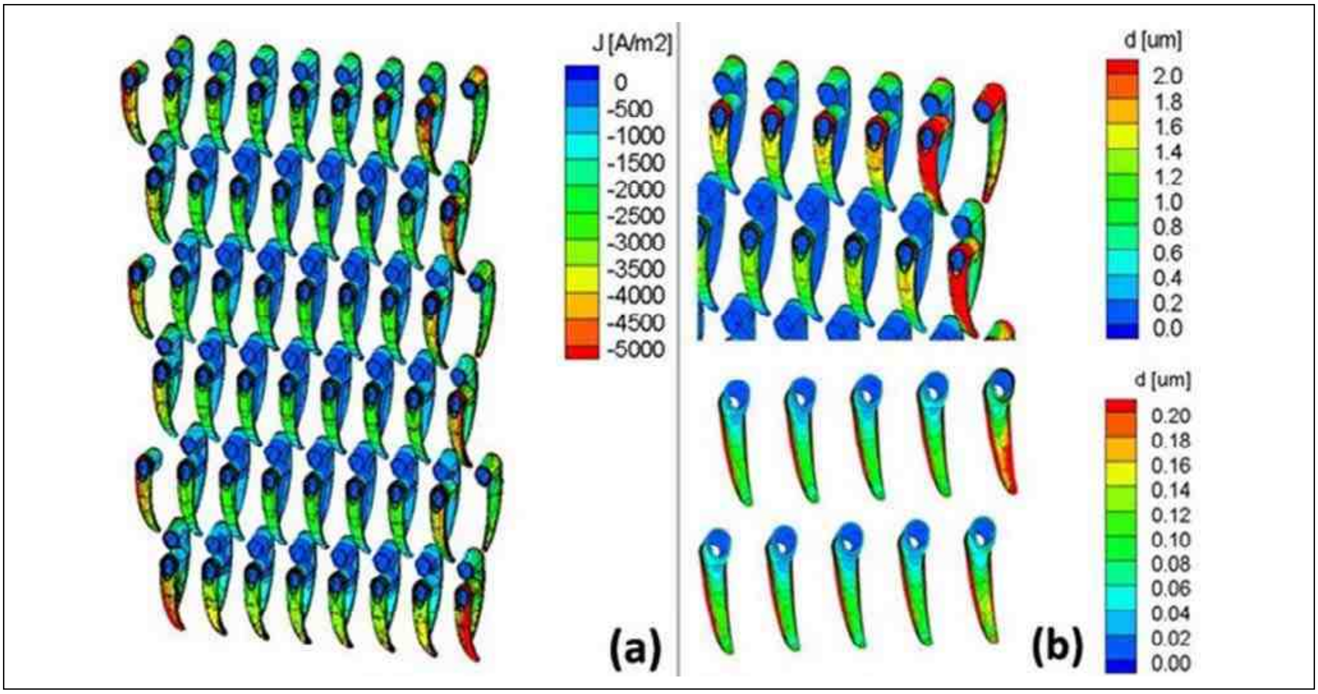

Figure 5—*(a) Chromium current density distribution; (b) Chromium layer thickness distribution.*

The table also mentions the load (number of parts on the rack) and the performance. Results will be illustrated in the next section for Case 1 (96 parts, poor performance), Case 2 (96 parts, very good performance), and the eventual final selection, Case 9 (84 parts, very good performance).

Global rack optimization

Case 1

Case 1 is a configuration where the parts located on the back side are shifted over a small vertical distance (Fig. 6). In this way, the rack load still equals 96 parts to be plated per rack.

However, as is shown in Fig. 7, there is still poor throwing power to the back of the door handles. The dark blue regions indicate areas where the chromium deposit will not be high enough and will result in the yellowish nickel show.

Case 2

Case 2 is a configuration with six columns and eight rows (Fig. 8). In this way, the load again equals 96 parts, but unfortunately the vertical dimension is exceeded (the parts exceed the boundaries of the blue box representing the maximum package as set by the customer).

Note the higher deposit thickness compared to Case 1, as there are no dark blue regions in Fig. 9. Case 2 gave the better performance, but the part load did not remain within the vertical plating package and could therefore not be retained.

Table 4

Overview of different rack configurations

	Description	#parts/rack	Performance
Case 1	Parts at back side of rack shifted over small vertical distance Δy	96	Poor
Case 2	6 columns, 8 rows	96	Very good
Case 3	7 columns, 6 rows	84	Good
Case 4	7 columns, 5 rows	70	Good
Case 5	Parts at back side of rack mirrored from front side, no horizontal shift Δx between different rows	96	Reasonable
Case 6	Alternating 8 parts per row and 7 parts per row	90	Reasonable
Case 7	7 rows, alternating 7 and 6 parts per row	92	Good
Case 8	8 rows, alternating 6 and 5 parts per row	88	Good
Case 9	6 columns, 7 rows	84	Very good

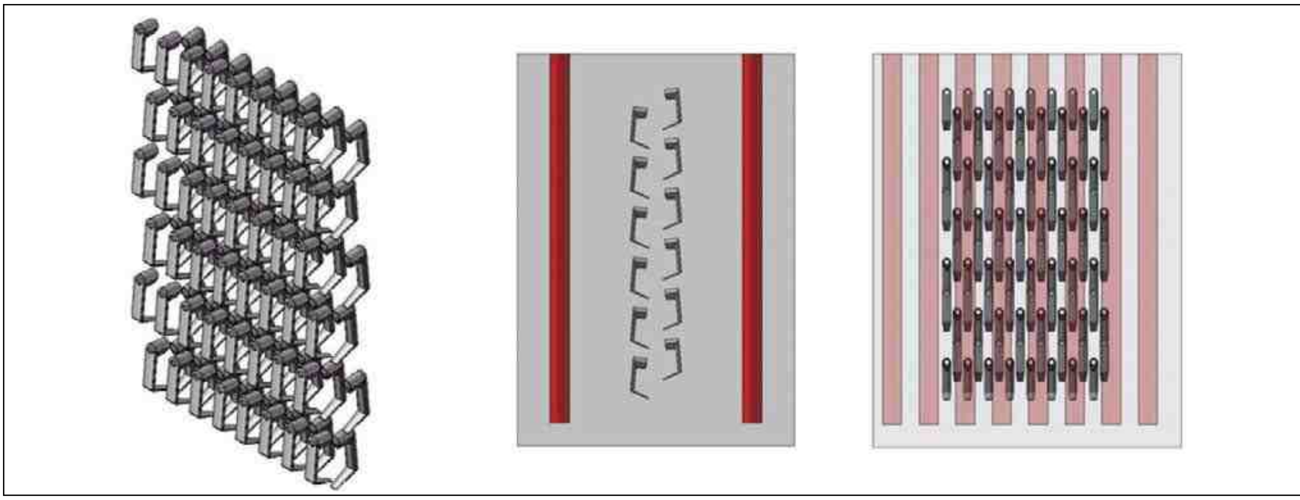

Figure 6—*CAD of nickel and chromium tank load, Case 1.*

Figure 7—*Chromium layer thickness distribution over lower parts on rack, Case 1.*

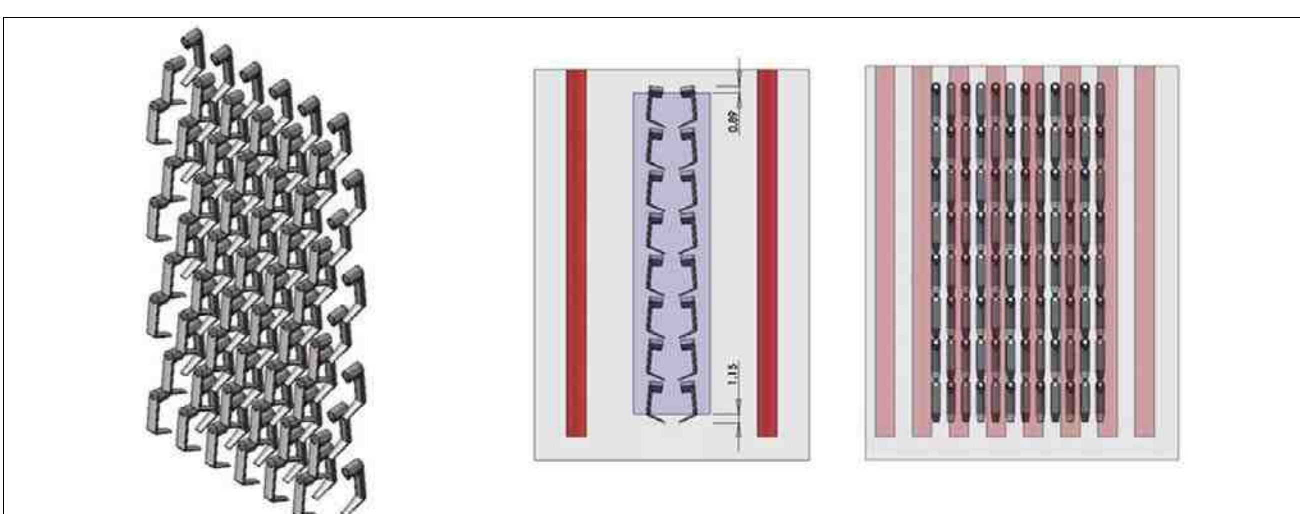

Figure 8—*CAD of nickel and chromium tank load, Case 2.*

Figure 9—*Chromium layer thickness distribution over lower parts on rack, Case 2.*

Case 9

Finally, Case 9 was proposed as the optimal configuration. The load however, had to be restricted for this configuration to 84 parts divided as two times six columns times seven rows (Fig. 10).

Nonetheless, this rack configuration gives the best performance in terms of deposit thickness (Fig. 11) and product quality.

Conclusions for global rack configuration optimization

Table 5 indicates the resulting probability of defects for all door handle designs in the final selected configuration as compared to the initial one.

To summarize, the initial configuration had:

- A load of 96 parts
- A very high probability of defects
- And 42% of the 96 parts affected with defects,

whereas the new rack configuration has:

- A load of 84 parts,
- Very low probability of defects
- And a maximum of 5% of the 84 parts affected with defects.

Table 5

Overview of different rack configurations, optimized situation

Part	Probability of Defect				
	Rough Copper	Chromium Burn	Nickel Show	Nodular Ni Growth	Rectifier ΔV out of range
Design A	Low	Medium	Low	Low	Low
Design B	Low	Medium	Low	Low	Low
Design C	Low	Medium	Low	Low	Low
Design D	Low	Medium	Low	Low	Low
Design E	Low	Low	Low	Low	Low
Design F	Low	Medium	Low	Low	Low
Design G	Low	Medium	Low	Low	Low
Design H	Low	Low	Low	Low	Low
Design I	Low	Medium	Low	Low	Low
Design J	Low	Low	Low	Low	Low

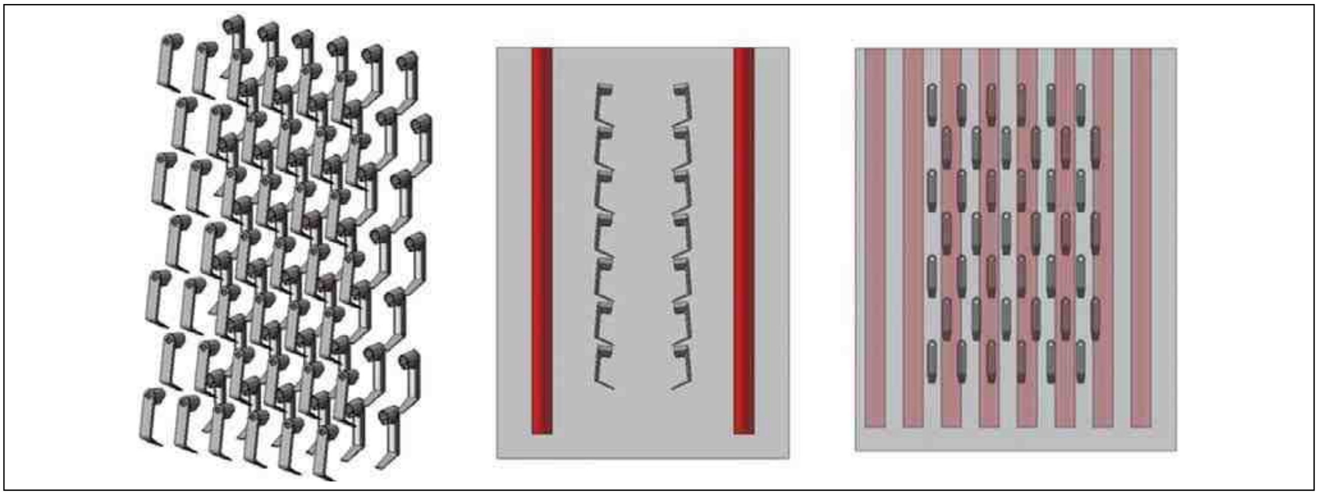

Figure 10—*CAD of nickel and chromium tank load, Case 9.*

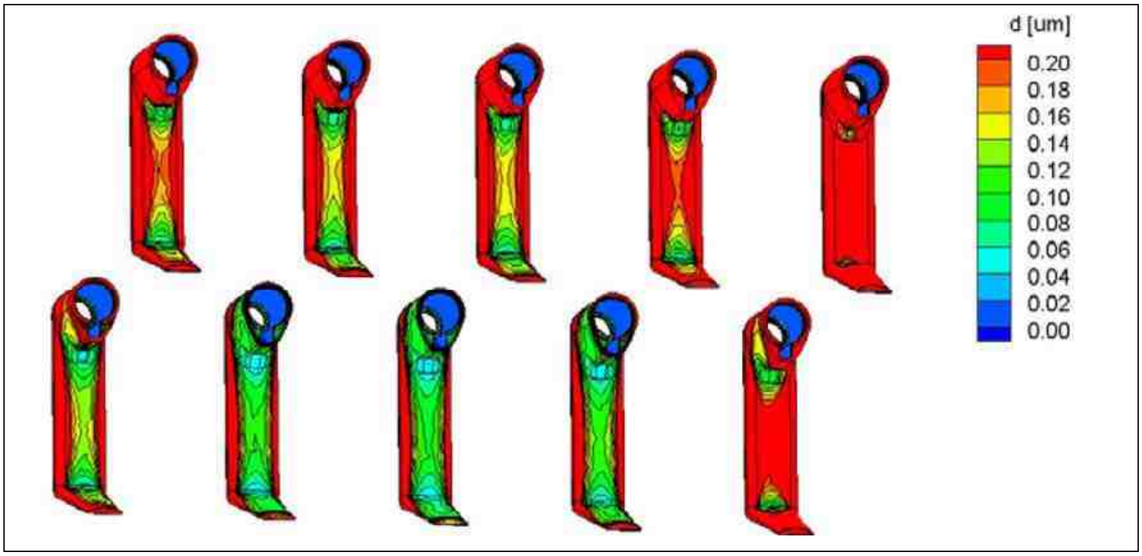

Figure 11—*Chromium layer thickness distribution over lower parts on rack, Case 9.*

Further local optimization: intelligent rack shielding

As illustrated above, the way that the parts are distributed over a rack has been optimized, ensuring a rack configuration where all door handle parts receive more or less similar current densities. Nevertheless, further local optimization to improve the layer thickness distribution over one single part is possible. For this purpose, "intelligent" tooling, such as current robbers, auxiliary anodes or shields, can be designed through software simulation.

In this case, the focus is on intelligent shielding. The design of current robbers is not feasible because the racks are multi-purpose (serving all ten door handle types), while the use of auxiliary anodes is not accommodated for in the design of the plating lines concerned here.

With dedicated shielding, the layer thickness values can be brought much closer to the specifications listed in Table 1 for the different metal layers, on "A" and "B" type surfaces. Also, shields enable a drastic reduction of defects caused by peak current density values above the maximal allowable values.

Another advantage is the material savings that can be obtained. The shields enable a reduction of the layer thickness on frontal "A" type surfaces, while maintaining the same or higher deposit at the other surface areas of the parts.

For the semi-bright nickel plating step for the part configuration of Case 9, Fig. 12 illustrates how intelligent shielding, designed with the simulation platform, can help to improve uniformity and avoid defects on a single part. The minimal layer thickness criterion of 13 μm (0.51 mil) for semi-bright nickel is now met at the flanks of the part, in sharp contrast to the situation without dedicated shields. At the same time, the high current density area (in red on the left), is reduced to orange except for a small part near the flank. Also, the dark blue spot on the backside is drastically reduced.

From an operational point of view, the shields could simply be hooked up to the rack after the door handle parts are loaded. Similarly the shields are removed before the rack is unloaded.

Shields could be considered later in a program as a way of further process improvement, or indeed, as a retro-fitting option for other part programs. Detailed analysis and description of the intelligent shielding design is beyond the scope of this paper.

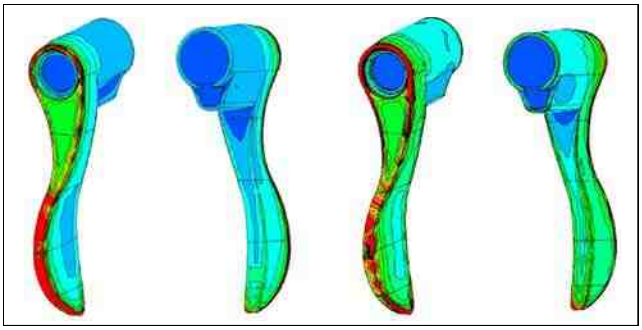

Figure 12—*Semi-bright nickel layer thickness distribution without (left) and with dedicated shielding (right).*

Final conclusions

The above rack design case clearly illustrates the power of CAE engineering. The challenge to design a rack suited for decorative chromium plating of ten different door handle designs, accounting for the objectives of minimal scrap and maximal productivity, was met by making use of advanced simulation technology.

It goes without saying that a trial-and-error approach as often used in actual daily practice is much too time and money consuming. A typical trial wet run comprises the following steps:

1. Improve the design of the rack (based on experience/feedback from previous test runs or from production)
2. Refurbish an existing rack (or build a completely new rack)
3. Make a series of production runs with the newly built/improved rack
4. Undertake visual inspection and destructive testing on a number of sample parts

Considering the time and expense required to fabricate and test a rack design in practice, such an approach can easily take two to three weeks, involving the consumption of energy, chemicals and actual components/parts to test and measure. CAE needs no pilot plant facility, requires only the part and rack CAD and takes only one to two days to evaluate a rack design.

Simulation of the initially proposed rack configuration enabled one to indicate the probability of defects for the different door handle designs with respect to chromium burn, nickel show, nickel nodular growth and the rectifier being out of range. The potential scrap rate for the proposed rack design was unacceptable and led to a program of further design and optimization.

Alternative rack configurations were defined and simulated to judge the improvement versus the initial rack configuration. On the rack configuration finally selected, the number of parts on one rack was reduced from the initial number of 96 to 84, but the realized savings were significant because of the enormous scrap fraction reduction, which led to additional benefits of increased yield, shorter lead times, metal savings and reduced costs for waste and water treatment.

Further local optimization is possible making use of intelligent shields on the rack. These shields again are designed with the same simulation platform.

The use of simulation technology ahead of production has proven to be a valuable decision-support tool to steer the production process and allows saving considerable time and money.

About the authors

Dr. Bart Van den Bossche graduated from the Vrije Universiteit Brussel (VUB, Belgium) with a M.Sc. degree in Metallurgical Engineering in 1991. He received a Ph.D. in Electrochemical Engineering in 1998. Bart is Elsyca's Engineering Manager for Surface Finishing projects. Bart has been active in electrochemical process computer modeling for over 15 years, as reflected in a series of peer reviewed papers. In addition, Bart has a long track record as a consultant for electrochemical cell and tooling design in the plating, electroforming and electrochemical machining industry. As Elsyca co-founder, Bart is in charge of several Elsyca consulting projects.

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